

Two New Aircraft Traffic Surveillance Symbology Concepts: Range Filter and Inboard Field-of-View Symbology

*Douglas T. Wong and Lynda J. Kramer
Langley Research Center, Hampton, Virginia*

*R. Michael Norman
The Boeing Company, Long Beach, California*

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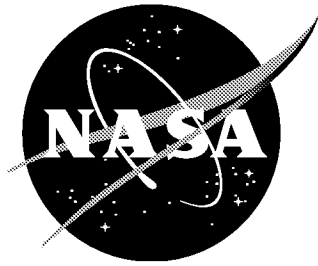
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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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Abstract

The purpose of the eXternal Visibility System (XVS) effort for NASA's High-Speed Research Program was to determine and to provide required pilot visual information for a High Speed Civil Transport vehicle concept to allow safe and efficient operation in the absence of forward windows. The objective of this preliminary experiment conducted at NASA Langley Research Center was to investigate two head-up surveillance symbology (HUSS) display issues. The first issue was concerned with the benefits of adding a range filter to the current HUSS concept. A range filter limits the amount of traffic symbols displayed head-up by setting a range boundary (e.g., 7-nmi) around the ownship. The second issue was concerned with the need to incorporate HUSS in the inboard field-of-view (IFOV) display of the XVS concept. The hypothesis tested was that adding a range filter to the XVS display and HUSS to the IFOV display would enhance the pilot's effectiveness in traffic surveillance tasks. Using a high-resolution graphics flight simulator, each of three pilots flew departure and arrival scenarios under visual meteorological conditions. The pilots' main tasks, while managing flight path, were to detect and assess potential airborne traffic hazards and to maintain overall situation awareness. Upon completing all the runs, each pilot completed a subjective questionnaire. Results showed that having both the HUSS on the IFOV and the range filter on each of the XVS displays enhanced the effectiveness of the XVS surveillance display concept. This configuration had the least head down time and the lowest mental workload. Combining both features gave the best target detection and, the earliest threat recognition performances, and enabled the pilots to create a better strategy for evasive action when it became necessary.

Introduction

An experiment entitled head-up surveillance symbology (HUSS) was conducted in January 2000. This experiment was a portion of the eXternal Visibility System (XVS) effort under the High-Speed Research Program. The program was intended to develop the necessary technologies for the next generation supersonic civil transports. The XVS effort was focused on a concept to provide forward visibility in the absence of forward windows for pilots of the High Speed Civil Transport (HSCT). This absence of forward windows made feasible the decision to not droop the nose of the HSCT, providing considerable savings in weight, cost, and mission constraints.

This experiment was conducted to investigate two HUSS display issues. The first issue was concerned with the benefits of adding a range filter to the current HUSS concept. A range filter limits the amount of traffic symbols displayed head-up by setting a range boundary around the ownship, outside of which, no non-threatening traffic symbol is displayed. The second issue involved the need to incorporate HUSS in the head-up Inboard Field of View (IFOV) display. The addition of an IFOV display was explored in a study by Dr. James R. Comstock (yet undocumented). This study investigated the addition of a conformal IFOV display to the HSCT's cockpit, thereby extending the pilot's visual Field-of-View (FOV) when flying head-up. This display presents to the pilot that portion of the forward view that the copilot views through his side window. Figure 1 is a schematic of the pilot's side of the XVS concept. The hypothesis tested in the present study was that adding a range filter to the XVS display and HUSS to the IFOV display would enhance the pilot's effectiveness in traffic surveillance tasks.

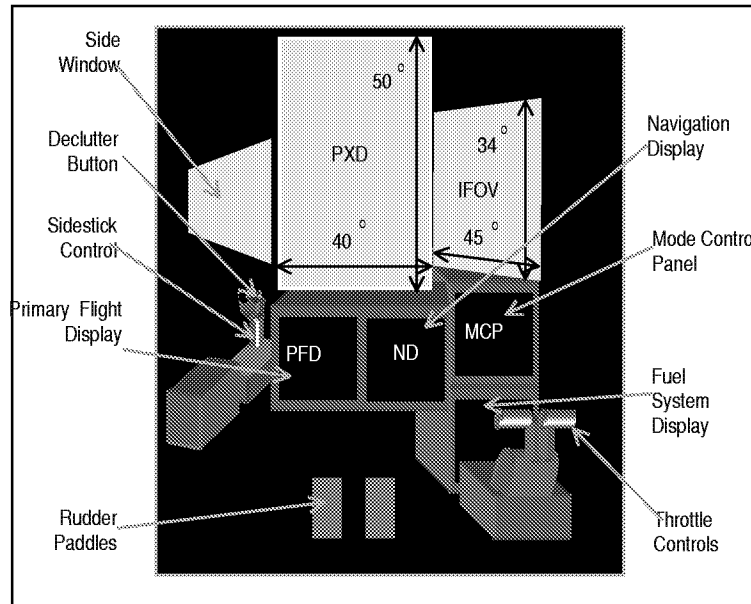


Figure 1. High Speed Civil Transport's External Visibility System

HUSS on Primary XVS Display

Prior to the addition of the IFOV display, Kramer and Norman (ref. 1) of NASA Langley Research Center (LaRC) examined the benefits of providing HUSS on the HSCT's head-up Primary XVS Display (PXD). Their results indicated that providing HUSS on the PXD improved the pilot's ability to detect and assess potential airborne traffic hazards.

HUSS Definition

Traffic	Description	Symbol
Proximate Traffic	Non-threatening ≤ 1200 ft relative altitude	
Traffic Advisory (TA)	≤ 1200 ft relative altitude, $< .2$ nmi range at Closest Point of Approach (CPA), time to CPA < 45 seconds	
Resolution Advisory (RA)	Estimated miss distance < 750 ft, $< .1$ nmi range at CPA, time to CPA < 30 seconds	

Range
- in nautical miles

Relative altitude
- in 100 feet
- displayed either at the top OR bottom

Vertical Speed Arrow
- displayed when $|V \text{ speed}|$ above 500 ft / min
- shows the traffic is either ascending OR descending

Figure 2. Head-up surveillance symbology (HUSS) definition.

The HUSS definition uses the standard TCAS symbology set except that the symbols are modified to a hollow design to avoid occluding critical information on the display. HUSS is generated when the ownship encounters traffic conditions that fall within one of the following alert categories: the proximate traffic alert, traffic advisory (TA) alert, and resolution advisory (RA) alert. Figure 2 provides a detailed definition of the various traffic alert categories. Like the head-down ND, the same HUSS definition is used to represent traffic from different surveillance sensor types (the XVS concept included surveillance information from various sensor sources, including TCAS and air-to-air object detection algorithms applied to modified x-band weather radar and visible-band imaging cameras). A traffic symbol varies in size with range as the traffic enters a 5-nmi boundary with the ownship. However, the size of the associated alphanumeric text remains constant at all times. Furthermore, the size of the range filter is 7 nmi¹. Aircraft generating TA and RA alerts are considered threatening traffic and hence are presented to the pilot whenever they occur.

Having HUSS on IFOV Display?

Dr. Comstock's IFOV display work identified the potential need to incorporate the HUSS onto the IFOV display. The benefit of display symbology on the IFOV must be carefully weighed against the potential for creating clutter on that display. The presence of clutter is particularly objectionable in a high traffic situation. Therefore, any candidate for enhancing traffic detection that involves additional symbology should ensure the control of clutter. Prior to the experiment, a literature search was carried out to gain some understanding on the issue of display clutter. This section summarizes the result of this activity.

Display Clutter

Many studies have covered the topic of display clutter. One example is Ruffiner et al's 1992 study on superimposing symbology on night-vision goggles (ref. 2). They suggested that there is a tendency for the pilots to serially process the displayed information. Furthermore, the pilots are inclined to attend more to the symbology than to the outside scene. Pilots tend to perceive changes in the symbolic elements of the display quicker, resulting in greater attention to those elements. Their study therefore seems to infer that misuse of head-up symbology could lead to display clutter.

Wicken and Long (ref. 3) in their paper on conformal symbology and attention shifts suggested that Head-up Display (HUD) conformal symbology enables faster transition to visual flight references due to the reduced scan time between symbology and outside scene. However, this concept seems to produce a clutter effect that slows detection of an unexpected far-domain event from a far-away distance. Therefore, caution needs to be exercised when adding additional symbols on the XVS, as was intended to do in this experiment. Nevertheless, their study showed that the pilot's ability to divide attention between HUD symbology and the external scene does improve with experience. One method to reduce clutter is to employ a declutter capability, either manually, or automatically.

In Dudfield's study (ref. 4) on using an interactive and flightpath-predictive declutter capability; the subject pilots were allowed to remove an artificially introduced display inaccuracy (symbology drift and lag) by pressing a stick button. Most pilots tended to realign the cue and

¹ A summary of the pre-experiment workshop where the range filter value was defined can be found in the document entitled: "Head-up Surveillance Symbology Workshop" by D. T. Wong.

obstacle when they became separate objects. In particular, cue drift was cancelled more quickly when there were multiple obstructions because matching the cues with the obstructions became more difficult.

Limiting the Traffic Display Range to Reduce Clutter

Merwin's document on traffic symbology study for XVS (ref. 5) suggested four schemes to reduce traffic symbology clutter. Most of these schemes were based on the idea of filtering. Among them were a *Range Filter* such as the one studied in this experiment; a *Threat Filter* that only displays traffic that attains some threat level (like TCAS); a *Time-to-closest-approach Filter* that offers information for planning avoidance maneuvers, but is encompassed at least partially within TCAS algorithms; and a *Pilot-selected Filter* that only displays traffic selected from the navigation display by the pilot.

The objective of Merwin's experiment was to address a 5-nmi range filter for the XVS. Unfortunately, he was unable to complete his study. Nonetheless, his limited study appeared to indicate that the range filter was valuable with respect to traffic detection and situation awareness.

Much research has touched on the issue of traffic display range. In J. W. Andrew's 1996 study of a head-down TCAS in the Long Ranger Helicopter (ref. 6), he mentioned that pilots preferred to limit the amount of traffic symbology by a variable range display. His conclusion was that for helicopters, the display of traffic beyond 3 nmi in range was seldom useful because it decreased display readability and increased clutter problems for the nearby traffic that was usually of most interest. Besides limiting the display range, his work also pointed out that a traffic detection criterion based on vertical tracking would be useful in lowering the rate of conflict alarms.

Dudfield (ref. 4) pointed out that the subject pilots in her study were typically satisfied with a surveillance display range of 5 km (2.7 nmi) for providing sufficient situational awareness and minimizing display clutter. However, optimum range was felt to be dependent on the ground speed.

E. E. Geiselman and R. K. Osgood in their 1995 Helmet-Mounted Display (HMD) work for military jet fighters (ref. 7) applied a 5-nmi target range to the HMD. Notice that the 5-mile threshold target range was larger than the 5-km range suggested by Dudfield (ref. 4). When combining with the work by Andrew (ref. 6), one can infer that the display range is highly dependent on the ownship aircraft type and its operational environment.

All of the studies reviewed above therefore suggest that a range filter is one method to automatically reduce the clutter created by traffic surveillance symbology. Although this method has been suggested in the literature, definite proof of the benefit of this concept does not exist. Consequently, this research effort was initiated to determine whether a Range Filter could reduce clutter and simultaneously provide better traffic detection for the XVS display.

The Experiment

Experiment Equipment

The experiment was conducted at LaRC's Visual Imaging Simulator for Transport Aircraft Systems (VISTAS-3). VISTAS-3 is a piloted fixed-base simulation facility enabled by

projection display systems. Two projected 36-degree horizontal by 26-degree vertical instantaneous FOV displays were employed as the left and right side windows. The primary XVS display (PXD) had a projected 40-degree horizontal by 50-degree vertical FOV. A 45-degree horizontal by 34-degree vertical FOV display located adjacent to the PXD simulated the IFOV display. Both displays, presented at a resolution of 50 pixel/degrees, consisted of simulated high-resolution camera video imagery, and symbolic information was provided on the PXD using the HSR Flight Deck Minimum Symbolology (FDMS) set. Horizon line and heading scale were the only symbology elements present on the IFOV display at all times.

There were four head-down liquid-crystal displays (LCDs) representing the Primary Flight Display (PFD), Navigation Display (ND), Mode Control Panel (MCP), and the Fuel Systems Display (FSD) respectively. The VISTAS-3 laboratory is supported by two Silicon Graphics multi-channel Onyx graphic systems which provided all the visual sources (including the head-down instrumentation), hosting of the aircraft model, and all input/output functions to the workstation. The simulator's control laws approximated the HSCT's dynamics and engine performance during approach and departure phases. A spring-loaded sidestick controller was the primary control inceptor in this experiment. There was a red button on the sidestick which functioned as a declutter switch. When the button was pressed, all symbology (PXD and IFOV) disappeared until the button was released.

Subjects

Three NASA LaRC in-house pilots were involved in this experiment as test subjects. They each had over 10 years of experience in flying various types of aircraft such as glass-cockpit transports and experimental aircraft with head-up displays and synthetic vision displays.

Scenarios

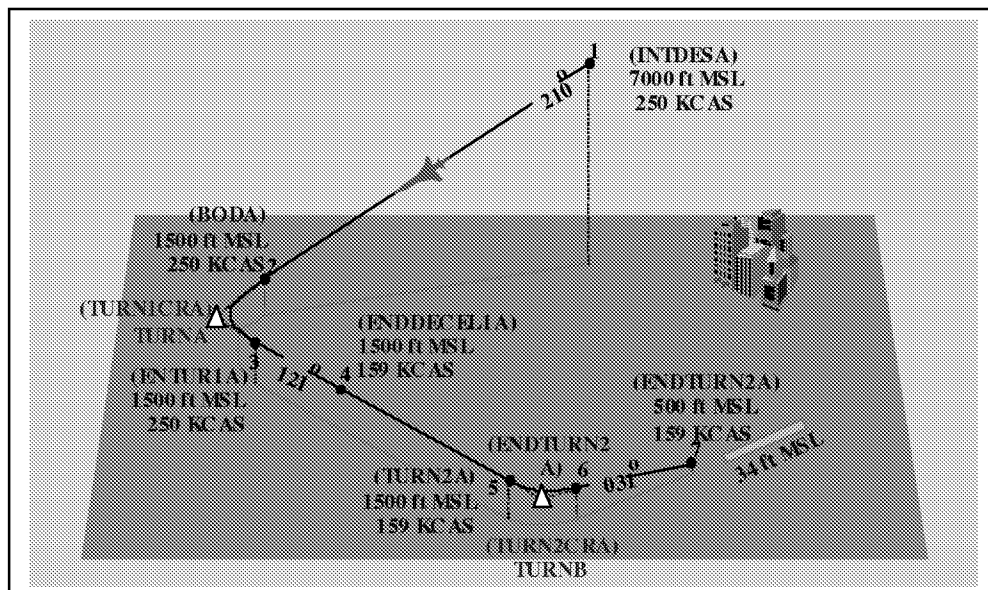


Figure 3. The approach scenario.

Each pilot flew two simulated scenarios, a departure and an arrival, under Visual Meteorological Conditions. The scenarios were medium (24,000 ft MSL) to ground level approaches and departures to NASA Wallops Airfield. Each scenario lasted approximately 9

minutes. Autopilot and autothrottle were engaged in every run. The approach scenario, as depicted in Figure 3, began from a descent at 7000-ft MSL at 250 KCAS to 1500 ft. After a turn at 1500 ft to the base leg, the aircraft initiated a deceleration to 159 KCAS. Several minutes after the deceleration, another turn was made to the final approach segment. A descent from 1500 ft to the runway threshold at 500 ft was then made to end the scenario. For the departure scenario, shown in Figure 4, the aircraft began at the end of the runway at 1500-ft MSL and 159 KCAS with the landing gear retracted. Several minutes into the simulation, the aircraft began accelerating to 250 KCAS. Upon completing the acceleration, the aircraft made a 45-degree right hand turn before climbing to 7000 ft MSL to end the scenario.

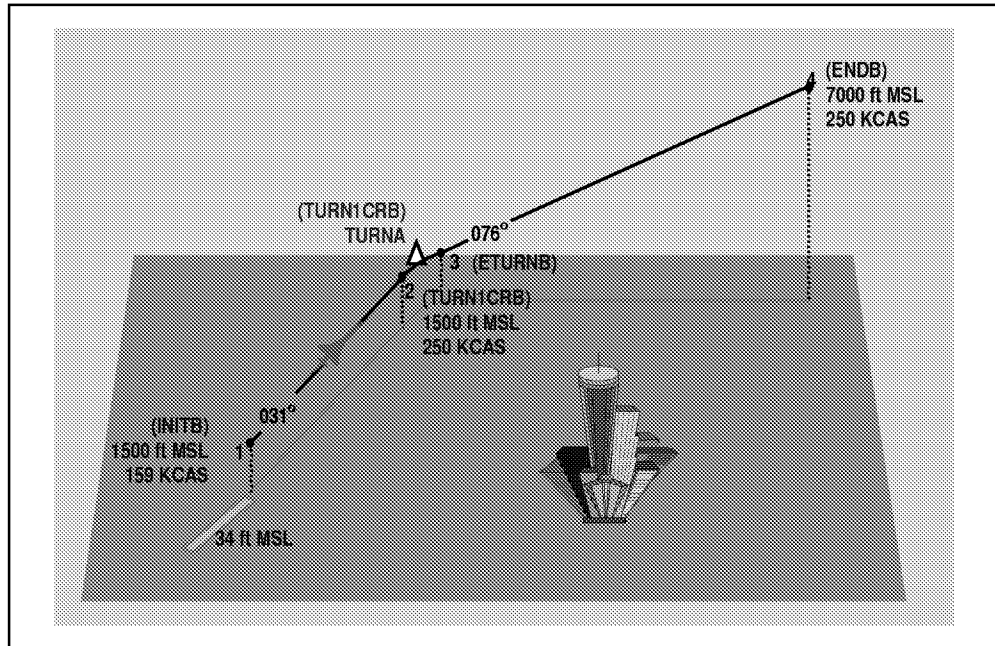


Figure 4. The departure scenario.

There were 15 traffic aircraft in each scenario. The traffic types, performances and sizes were configured to resemble Beechcraft-200s, Boeing-737s, and HSCTs. Traffic began to appear approximately 5 minutes into each run in a clutter formation. This multi-aircraft set up was intended to allow a more effective evaluation of both the range filter and the IFOV display HUSS simultaneously. The same encounter geometries were used for the traffic in each run, though the order of the aircraft's appearance varied. A plan view of traffic information was provided on the head down ND at all times. Pilots were allowed to touch the traffic symbols on the ND to display the corresponding traffic type and speed information on the ND. In addition, touching traffic symbols on the ND displayed the head-up traffic symbol on the XVS displays (PXD and IFOV), regardless of the current traffic category and the size of the range filter.

Detecting and assessing potential airborne traffic hazards while managing flight path and maintaining overall situation awareness along the flight path were the pilots' main tasks. Besides the main tasks, each pilot was also required to carry out a secondary fuel-monitoring task to increase workload. His job was to ensure the amount of fuel in each tank was within 2000 pounds of each other by manipulating the controls on the FSD. A simulated leak rate of 1000 pounds per minute was introduced to either the left or the right tank. This leak forced the pilot to perform a fuel transfer task. The fuel imbalance did not actually affect the ownship's performance or flying qualities. Upon completing all the runs, each pilot was asked to complete a questionnaire. In

essence, the questionnaire asked the pilots to rate the effectiveness of various HUSS symbology combinations and to provide their opinions on these concepts.

Experiment Design

In each run, the pilot was exposed to either an arrival or a departure scenario to simulate traffic surveillance events against backgrounds of ground or sky textures in different speed regimes. A scale that rates the subjective effectiveness of the various XVS HUSS concepts was used as a measure of the dependent variable.

The treatment factors in this experiment were the “Range Filter” and “HUSS on the IFOV Display”. Four combinations, “with” or “without” the treatment factors, were presented to the pilots. For the “Without Range Filter” and “Without HUSS on IFOV Display” combination, the resulting HUSS configuration provided only TA and RA categories of information. This combination represented the current HUSS definition in which only traffic considered threatening (generated TA or RA alerts) was displayed on the PXD. The pilot could display proximate traffic momentarily on the PXD by pressing that individual traffic symbol on the touchscreen ND. The HUSS was available on the PXD only. There was no traffic information at all on the IFOV. The “Without Range Filter” and “With HUSS on IFOV Display” combination was the configuration in which both the PXD and the IFOV display had TA and RA categories of traffic information. However, Proximate Traffic information was not available to either the PXD or the IFOV display unless the pilot pressed individual traffic symbols on the ND. The “With Range Filter” and “Without HUSS on IFOV Display” combination represented the condition in which only the PXD had a 7-nmi range filter for displaying Proximate, TA, and RA categories of traffic information. There was no traffic information at all on the IFOV display. Finally, the “With Range Filter” and “With HUSS on IFOV Display” combination was the configuration in which the range filter was applied to both the PXD and the IFOV display. Traffic symbols of all categories (Proximate, TA, and RA) were therefore available to both displays.

Table 1 illustrates the order of the treatment combinations for each pilot. It also indicates which fuel tank had the leak in a particular treatment combination. The order of the treatment combinations was different for each pilot in order to reduce any learning effects and individual differences among the subjects.

Table 1. Test Sequence

Pilot	Test Sequence							
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th
1	A2, B2, L, A	A2, B1, R, A	A2, B2, L, D	A2, B1, L, D	A1, B2, R, A	A1, B1, R, A	A1, B2, L, D	A1, B1, R, D
2	A1, B2, L, A	A1, B1, R, A	A1, B2, R, D	A1, B1, R, D	A2, B2, L, A	A2, B1, L, A	A2, B2, L, D	A2, B1, R, D
3	A2, B2, L, A	A2, B1, R, A	A1, B2, L, A	A1, B1, L, A	A2, B2, R, D	A2, B1, R, D	A1, B2, L, D	A1, B1, R, D

Where:

- L = leak on the left fuel tank
- R = leak on the right fuel tank
- A = arrival scenario
- D = departure scenario
- A1 = without range filter
- A2 = with range filter
- B1 = without HUSS on the IFOV display
- B2 = with HUSS on the IFOV display

Hypothesis

The hypotheses tested in this experiment were the following: (1) adding a range filter to both XVS displays would enhance the pilot's overall effectiveness in traffic detection and avoidance; (2) adding HUSS to the IFOV display would also enhance the pilot's effectiveness in traffic detection and avoidance for traffic within the IFOV; (3) the XVS concept would be the most effective in traffic detection and avoidance when the range filter is combined with the HUSS on the IFOV display.

Results

Data Summary

After the experiment, a numerical scale (see figure 5) with values between 1 to 9 was assigned to the answers of the questionnaire given to each pilot. (See Appendix 1.) For example, a value of 1 was assigned to statements that the pilots rated "strongly disagree" or "highly ineffective", while a value of 8 was given to those rated between "agree" and "strongly agree" or between "effective" and "highly effective". Tables 2-4 contain a brief description of each question in sections I to III of the questionnaire and the corresponding ratings the pilots provided. Figures 6 and 7 provide graphical summaries for the same data presented in Tables 2-3. A two-way analysis of variance (ANOVA) was applied to the ratings from questions 3a to 3d of section III. The goal was to analyze the effects of the various treatment levels of the two factors and their interactions. Tables 5, 6, and 7 are respectively the scores, means/standard deviations, and ANOVA summary of this portion of the analyses. A graphical depiction of the question 3 result is shown in Figure 8. In addition to the summaries presented in this section, the raw data is provided in Appendix 1.

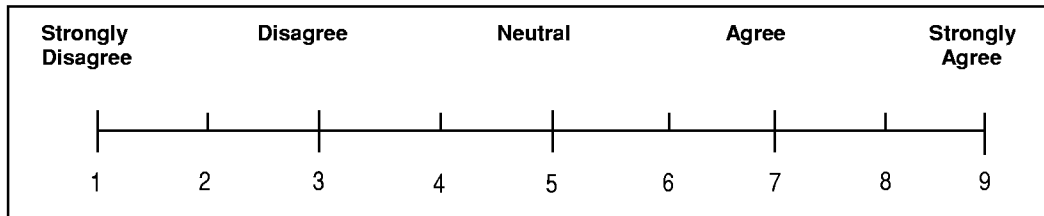


Figure 5. An example of the numerical rating scale used in the questionnaire

Section I Results: HUSS on the IFOV Display

Table 2. Description of Questionnaire Inquiries and the Pilot Ratings for HUSS on the IFOV Display

Question Number	Question Descriptions (HUSS on IFOV)	Pilot Ratings		
		S1	S2	S3
I.1	Increases traffic detection ability	9	9	9
I.2	Increases threatening traffic detection ability	7	8	9
I.3	Created too much clutter	3	2	3
I.4	Reduces workload	7	7	9
I.5	Increases awareness of nearby traffic	9	8	8

All pilots rated from “Agree” to “Strongly Agree” on questions concerning the traffic detection ability with the HUSS on the IFOV display. The pilots either “Disagreed” or “Strongly Disagreed” that having HUSS on the IFOV display created too much clutter. In general, the pilots thought that having HUSS on the IFOV display greatly enhanced their situational awareness and reduced their workload. It also reduced the need to hunt in order to distinguish a particular piece of traffic, especially when the pilot needed to make a turn towards the direction covered by the IFOV display. Two pilots thought that the same rules and properties used for HUSS on the PXD should apply to the HUSS on the IFOV display.

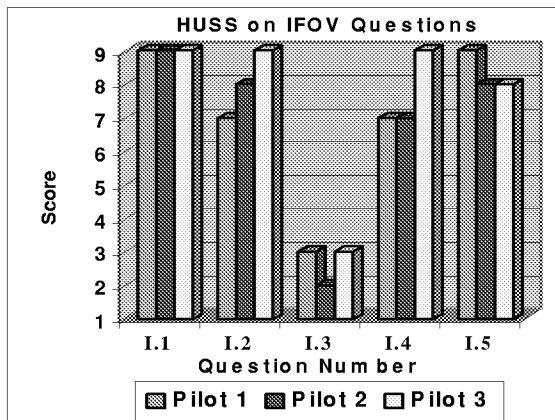


Figure 6. Numerical scores on questions in section I.

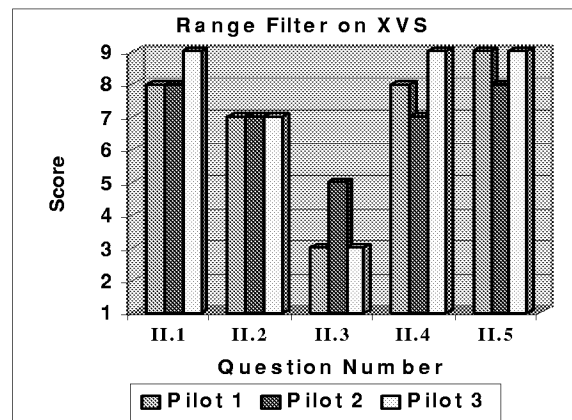


Figure 7. Numerical scores on questions in section II.

Section II Results: Range Filter on the XVS Displays (PXD and IFOV display)

Table 3. Descriptions of Questionnaire Inquiries and the Pilot Ratings for Range Filter on the PXD & the IFOV Display

Question Number	Question Descriptions (Range Filter on XVS)	Pilot Ratings		
		S1	S2	S3
II.1	Increases detectability of traffic nearby	8	8	9
II.2	Increases ability to assess potentially threatening traffic	7	7	7
II.3	Created too much clutter	3	5	3
II.4	Reduces workload	8	7	9
II.5	Increases awareness of nearby traffic	9	8	9

All pilots either “Agreed” or “Strongly Agreed” that having a range filter on both XVS displays increased their ability to detect traffic and at the same time reduced their workload. Two pilots “Disagreed” that the range filter created too much clutter. One of the pilots was “Neutral” on this issue.

Pilots generally thought the range filter reduced workload in a multi-aircraft environment by automatically displaying proximate traffic. The pilots also felt that adding the range filter reduced head down time because it greatly reduced the need to manually select aircraft on the ND, one-at-a-time, to display the corresponding HUSS symbol on the head-up XVS displays.

Section III Results: Range Filter on the PXD & the IFOV Display and HUSS on the IFOV Display

When the pilots were asked whether both the display options (i.e., adding a range filter to both XVS displays and HUSS on IFOV) should be added to the current display concept, pilots either put down “Agree” or “Strongly Agree”.

Table 4. Description of Questionnaire Inquiries and the Pilot Ratings for Range Filter on the PXD & the IFOV Display and HUSS on the IFOV Display

Question Number	Question Descriptions (Range Filter on XVS and HUSS on IFOV)	Pilot Ratings		
		S1	S2	S3
III.1	Both should apply to approach and departure	9	8	7
III.2	TA & RA should be transferred automatically to both XVS displays	9	8	9

Comparisons of the Four Display Configurations

Question III.3 was related to the effectiveness of different combinations of the new display concepts across both scenarios. (See Appendix 1.) A multi-factor analysis of variance procedure (ANOVA) was applied to find out if there were significant differences among the treatment combinations (referred to as 3a to 3d). Tables 5 and 6 provide a summary of the ratings and the corresponding means and standard deviations to those combinations. The ANOVA results are presented in Table 7.

Table 5. Descriptions of Questionnaire Inquires and Pilot Ratings of Section III.3

Question No.	Question Descriptions	Pilot Ratings		
		S1	S2	S3
3a	Effectiveness of w/o Range Filter and w/o HUSS on IFOV	3	5	3
3b	Effectiveness of w/o Range Filter and w HUSS on IFOV	5	7	4
3c	Effectiveness of w/ Range Filter and w/o HUSS on IFOV	6	6	5
3d	Effectiveness of w/ Range Filter and w HUSS on IFOV	8	8	9

Table 6. Means and Standard Deviations of the Results of Section III.3

	W/O Range Filter		W/ Range Filter	
	W/O HUSS on IFOV, (3a)	W/ HUSS on IFOV, (3b)	W/O HUSS on IFOV, (3c)	W/ HUSS on IFOV, (3d)
Mean	3.67	5.33	5.67	8.33
Std Deviation	1.1547	1.5275	0.5774	0.5774

Table 7. ANOVA Summary of Section III.3

Error Source	Degree of freedom	Mean Square	F	Significance ($\alpha=0.05$)	Observed Power
RANGE FILTER (RF)	1	18.75	17.31	0.003	0.952
IFOV HUSS	1	14.08	13.00	0.007	0.883
RF * IFOV HUSS	1	0.75	0.69	0.430	0.114
Error	8	1.08			
Total	11				

The ANOVA results in Table 7 indicate that both the range filter and the HUSS on the IFOV display were significant treatment factors. There was very little interaction between the two factors. The interaction term can be seen as the predictability of one of the factors when the magnitude of the remaining factor is held constant. The low value of the power of the test implies that only large interaction effects would have been detectable. Figure 8 is a graphical illustration of the result. It clearly shows that the display configuration with the range filter active and the HUSS on the IFOV display (condition 3d or point A2-B2 with a mean score of 8.33) was the most effective concept among the four combinations examined.

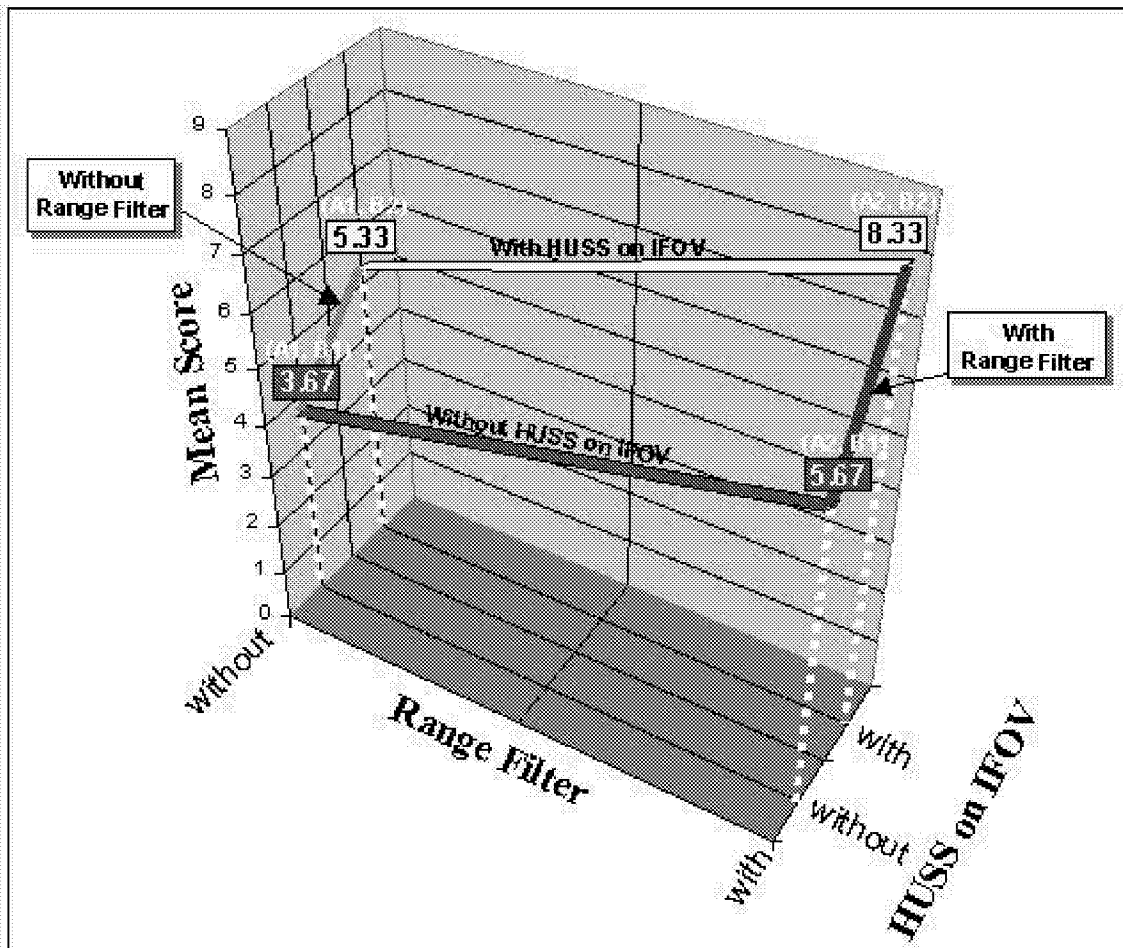


Figure 8. Mean effectiveness for the four display configurations.

Question III.4 asked pilots to record their opinions on workload for each of the four display configurations tested (4a to 4d). The following four sections summarize the pilots' response for each configuration.

Question III.4a: Without HUSS on IFOV and Without Range Filter on XVS

All pilots thought this condition created the highest workload. Two pilots rated this combination as "Ineffective" while one pilot rated it as "Neutral". They expressed that the area to the right of the aircraft is just as important as the area ahead of the aircraft. The HUSS helped direct the pilot's attention to the IFOV area if there was an aircraft there, whether threatening or

not, and thus increased the time available for other tasks. The lack of range filtering further exacerbated the problem, as the pilot had to spend more time looking for the traffic and mentally transferring bearing angles from the navigation display, one at a time, to the IFOV display.

Question III.4b: With HUSS on IFOV and Without Range Filter on either XVS display

Pilots liked this combination slightly more than the previous one. Two pilots gave ratings between “Neutral” and “Effective” while the remaining one gave it a “Neutral” rating. The pilots pointed out that the presence of HUSS makes the IFOV a much more useful display. It enhanced their ability to detect traffic. They thought that this combination had higher workload than the condition with the range filter available (treatment combination 4d, or A2-B2) because it did not allow automatic tracking of the proximate traffic.

Question III.4c: Without HUSS on IFOV and With Range Filter on PXD

The result was slightly mixed for this display combination. One pilot thought this concept was “Effective” while the other two pilots rated it as “Neutral” and “Slightly Ineffective”. On the average, therefore, this configuration was slightly less effective than the previous one. Pilots commented that the IFOV display was not as useful for traffic detection without the HUSS because aircraft could come from any bearing angle ahead of “abeam”. Having the HUSS on the IFOV display would add a little more safety than having the range filter only. The biggest disadvantage is the disappearance/absence of HUSS once the traffic moves from the PXD into the area covered by the IFOV display. When the traffic moves into the IFOV display, it can still be a threat.

Question III.4d: With HUSS on IFOV and With Range Filter on both XVS displays

All pilots gave this display combination very high ratings. They thought this configuration had the least head down time and the lowest mental workload. The combination of both features resulted in the best traffic detection, the earliest threat recognition, and the best situation awareness. This configuration also enabled the pilots to create a better strategy for evasive action when it became necessary. The only disadvantage may be increased clutter.

Question III.5: Additional Comments

This section requested the pilots to provide additional comments they might have related to the display concepts being studied in this experiment. These comments are valuable for improving the current XVS display concepts, or any future surveillance display concepts such as the displays for the upcoming Synthetic Vision System (SVS) for NASA’s Aviation Safety Program (AvSP).

(1) Display Concepts Recommendations

One comment was related to aircraft velocity predictions. A pilot suggested that the velocity vectors (which were a part of the TCAS symbol under all of the appropriate display configurations) on the traffic symbols should have a velocity dependent magnitude. This setup would allow the pilot to predict whether the traffic would stay within the FOV of the display or transition to another display.

For the current HUSS concept, the proximate traffic symbols being selected from the ND to appear on the XVS displays are not distinguishable from any other same category traffic once

the traffic enters the range filter's boundary. One pilot thought it would be desirable to have a scheme to highlight the selected traffic symbol on the head-up display. This would be very useful when Air Traffic Control gives a clearance in terms of following another aircraft. There was also a concern that the TA symbol of the HUSS could sometimes be confused with the glideslope and localizer pointers of the FDMS on the PXD.

While not all pilots thought clutter was a problem with the XVS display concept, a decluttering capability was thought to be "a must". The symbology was believed to be very helpful for traffic detection but slightly less so for threat determination. This diminishment is because the symbology helped with the bearing rate, but it was quicker (at close ranges) to determine the range rate by actually viewing the traffic. Doing so required decluttering the head-up display momentarily. One pilot recommended a two-position declutter switch. The first position would declutter the traffic symbols on the XVS displays and the second position would declutter all symbology, including flight symbology. This setup would be more important while flying the aircraft manually. Another declutter idea suggested was a pilot-variable range filter to declutter all symbols except any TA and RA category traffic. The range filter should have the ability to allow the pilot to select the range based on traffic conditions and phase of flight. For example, a larger range for cruise altitude should be available since the closure rates are much higher. The same scale values as the ones used on the navigation display, but operating independently, might be used for this concept.

(2) Experiment Design Recommendations

Most pilots thought that there were too many aircraft concentrated too closely together in this experiment even given the objective of the experiment. A more realistic distribution of the aircraft would still allow the experiment's objective to be met. In addition, a same-direction converging traffic would be a good test of the IFOV.

Conclusions

The answers to the questionnaires indicated that the pilots gave favorable ratings when the range filter was applied to the XVS display concept. Furthermore, according to the results, the HUSS should be applied to both the IFOV display and the PXD for the XVS surveillance display concept to be effective. The pilots' opinions were further confirmed by quantitatively analyzing some of the questionnaires' result with an ANOVA procedure. The analysis revealed that the treatment condition with both factors present (HUSS on IFOV and range filter on) was not only the most favorable but also statistically significant.

The subjective data gathered in this experiment imply that applying HUSS onto the IFOV display and having a range filter on both the PXD and the IFOV display enhance the effectiveness of the XVS surveillance display concept. Pilots' thought this configuration had the least head down time and the lowest mental workload. Combining both features gave the best traffic detection, the earliest threat recognition, and the best situation awareness. This configuration also enabled the pilots to create a better strategy for evasive action when it became necessary. The pilots also thought that the HUSS helped direct the pilot's attention to the IFOV area if there was traffic there, whether threatening or not. With the range filter, it was no longer necessary to spend extra time searching for the traffic and mentally transferring their bearing angles from the navigation display, one at a time, to the IFOV display. Therefore, the pilots had more time for other tasks.

The results of this study confirmed the following hypotheses: (1) adding a range filter to both XVS displays would enhance the pilot's overall effectiveness in traffic detection and avoidance; (2) adding HUSS to the IFOV display would also enhance the pilot's effectiveness in traffic detection and avoidance for traffic within the IFOV; (3) the XVS concept would be the most effective for traffic detection and avoidance when the range filter on both displays is combined with the HUSS on the IFOV display.

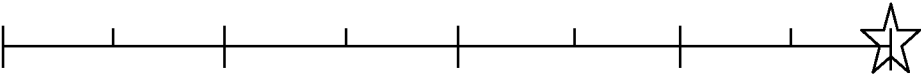
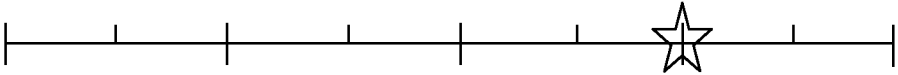
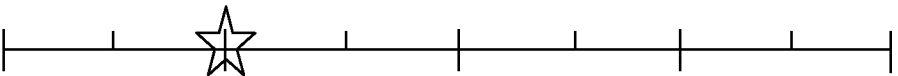
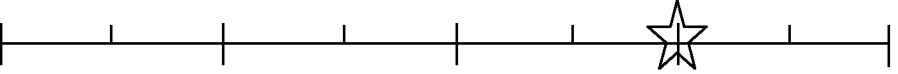
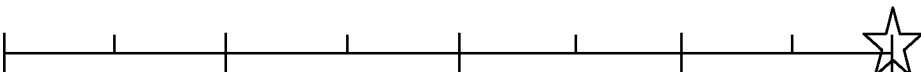
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2. Ruffner, John W.; Grubb, Monty G.; and Hamilton, David B.: *Selective Factors Affecting Rotary Wing Aviator Performance with Symbology Superimposed on Night Vision Goggles*. Army Research Inst. Report, ASI69034991, ARIRR1622, 1992.
3. Wicken, Christopher D.; and Long, Jeffry: *Conformal Symbology, Attention Shifts, and the Head-up Display*. Proceedings of the Human Factors and Ergonomics-Society, 1994, pp. 6-10.
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6. Andrew, John W.: *Pilot Evaluation of TCAS in the Long Ranger Helicopter*. Technical Report, Department of Transportation, FAA, DOT/FAA/PM-85/30, 1986.
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Appendix 1: The Workshop Questionnaire Results

Pilot 1

- I. Question 1 to 6 are related to the display concept of Head-up Surveillance Symbology (HUSS) on the In-board-field-of-view (IFOV) display (see Figure 1). On the line that follows each question, please place a mark that corresponds to your response.

1. Adding HUSS on the IFOV display increases your ability to detect traffic.
- Strongly Disagree Disagree Neutral Agree Strongly Agree
- 
2. Adding HUSS on the IFOV display increases your ability to assess whether traffic was potentially threatening.
- Strongly Disagree Disagree Neutral Agree Strongly Agree
- 
3. Adding HUSS on the IFOV display creates too much clutter on the display.
- Strongly Disagree Disagree Neutral Agree Strongly Agree
- 
4. Adding HUSS on the IFOV display reduces workload.
- Strongly Disagree Disagree Neutral Agree Strongly Agree
- 
5. Adding HUSS on the IFOV display increases your awareness of traffic in the vicinity of the ownship.
- Strongly Disagree Disagree Neutral Agree Strongly Agree
- 

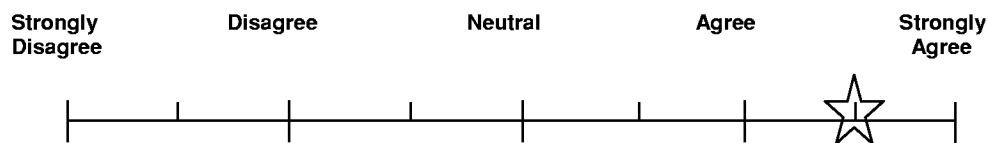
6. What is your general impression of having HUSS on the IFOV display?

I think it is highly desirable, for the same reasons it is desirable on the PXD. Declutter capability is a must.

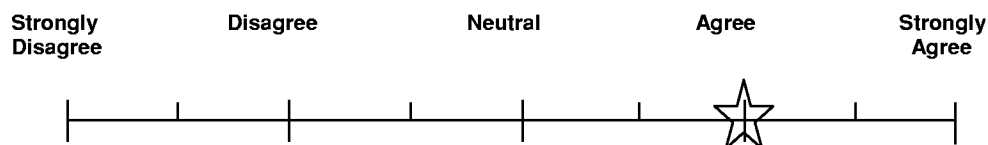
Symbology helps significantly with “detection”, but slightly less with “threat determination”. This is because the symbology helps with bearing rate, but it is quicker (at close ranges) to determine range rate from actual viewing of the target, which usually requires decluttering momentarily

II. Questions 1 to 6 are related to the Range Filter display concept. The Range Filter allows HUSS information to be displayed on the PXD and/or IFOV, depending on the test condition, within a 7 n.m. boundary of the ownship. On the line that follows each question, please place a mark that corresponds to your response.

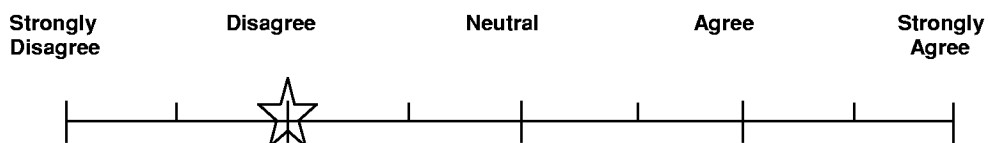
1. Adding a Range Filter increases your ability to detect traffic that is in close proximity to the ownship.



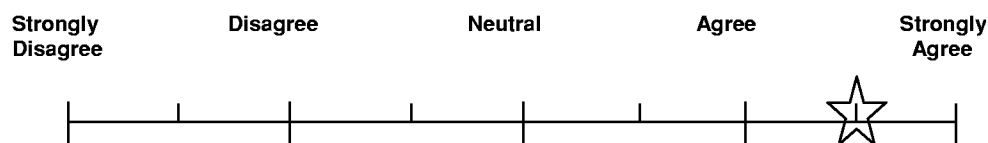
2. Adding a Range Filter increases your ability to access whether the traffic was potentially threatening.



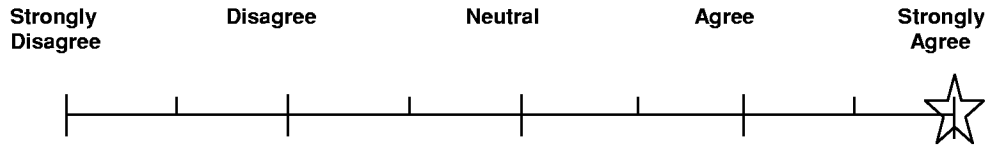
3. Adding a Range Filter creates too much clutter on the display.



4. Adding a Range Filter reduces workload.



5. Adding a Range Filter increases your awareness of traffic in the vicinity of the ownship.



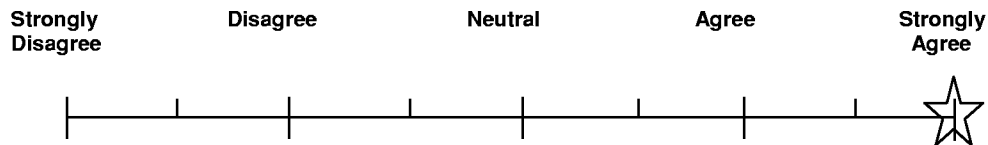
6. What is your general impression on the Range Filter display concept?

I like it. Adding automatic range filtering reduces my head down time because I do not have to manually select targets, one-at-a-time, to bring up the head-up symbology. It also allows me to scan multiple targets without having to refocus on the NAV display to see where the next threat is coming from.

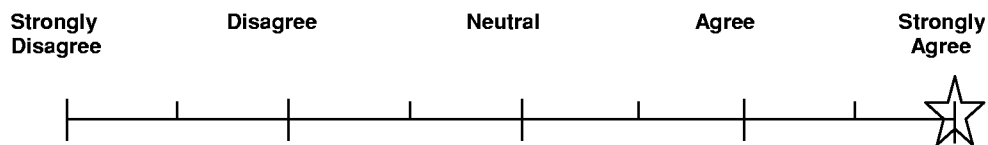
III. The following questions are related to both the display concepts of a 7 n.m. Range Filter on the XVS display* and HUSS on the IFOV display examined in this experiment:

**Note: XVS display refers to the combined use of the Primary XVS display (the primary head-up XVS display, or PXD), and the IFOV display. See Figure 2 below:*

1. The two display concepts examined in this experiment should be applied to both the approach and departure scenarios.



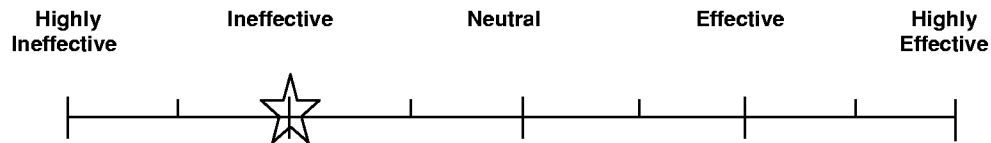
2. Traffic considered a threat or potential threat, i.e. TA and RA, should be transferred automatically from the Nav. Display to the XVS display (i.e. the PXD and the IFOV display).



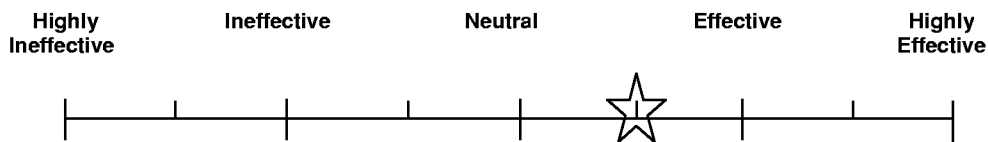
III. (Questionnaire Part III continues)

3. Please rate the overall effectiveness of the following display concepts for assessing and detecting traffic (see **Figure 2** for displays definitions):

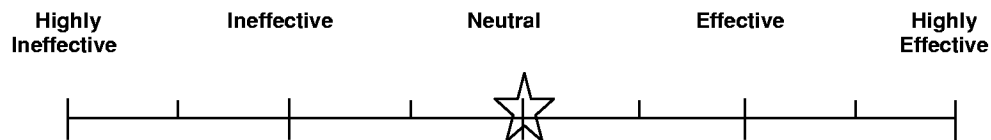
- a. **Without** HUSS on the IFOV and **Without** Range Filter on the XVS. (*This condition implies that the PXD contains only TA and RA categories information. There is no traffic information at all on the IFOV.*)



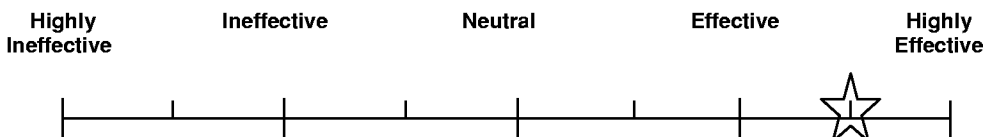
- b. **With** HUSS on the IFOV and **Without** Range Filter on the XVS. (*This condition implies that both the PXD and the IFOV have TA and RA categories traffic information but there is no Proximate Traffic information on both the PXD and the IFOV displays.*)



- c. **Without** HUSS on the IFOV and **With** Range Filter on the PXD. (*This condition implies that only the PXD has a 7 n.m. Range Filter for displaying Proximate, TA, and RA categories traffic information. There is no traffic information at all on the IFOV.*)



- d. **With** HUSS on the IFOV and **With** Range Filter on the XVS. (*This condition implies that the Range Filter is applied to both the PXD and the IFOV for displaying Proximate, TA, and RA categories traffic information.*)



4. Please discuss the **advantages and disadvantages** of the following display concepts. (See the previous page and Figure 2 for definitions of the terms.)

a. **Without** HUSS on IFOV and **Without** Range Filter on XVS

The area to the right of the aircraft is just as important as the area ahead of the aircraft. HUSS helps call the pilot's attention to the IFOV area if there is a target there, whether threatening or not. This helps with intelligent scanning and increases the time available for other tasks. Without HUSS, the pilot has to spend more time looking for the targets and mentally transferring bearing angles from the NAV display to the IFOV display.

Lack of range filtering further exacerbates the problem because the pilot has to spend time "fingering" targets to get them to come up on the HUSS which increases head down time and mental workload.

b. **With** HUSS on IFOV and **Without** Range Filter on XVS

If I could only have one of these improvements, I would pick HUSS on the IFOV over range filtering because it is such a significant aide in target detection. However, both concepts lower workload and reduce head down time. So I would have them both turned "on" in my aircraft.

c. **Without** HUSS on IFOV and **With** Range Filter on PXD

This configuration added a lot in this experiment because most of the targets were in the PXD. However, in the real world, targets are most likely going to be less densely packed and may be a threat from any bearing angle ahead of "abeam". In this circumstance, I think HUSS on the IFOV display would add a little more safety than range filtering on both displays, but both are very desirable as long as there is a decluttering button.

d. **With** HUSS on IFOV and **With** Range Filter on XVS

This is the optimum. The combination of both features gives the best target detection, the earliest threat recognition, the best situation awareness (and associated strategy for how best to maneuver if that becomes necessary), the least head down time, and the lowest mental workload.

5. Please provide additional comments, if there is any, regarding to this experiment.

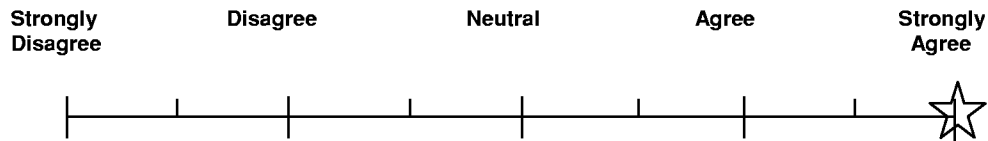
I would like a two-position declutter switch. The first position would declutter the targets on the XVS and the second position would declutter all symbology including flight symbology. This would be more important while hand-flying than while on autopilot.

When range filtering is on, there needs to be a way to "highlight" specific targets in the HUSS when they are selected on the NAV display. If ATC gives a clearance in terms of another aircraft "following the United 747", the pilot needs to be able to ID that target on the NAV display and then transfer that ID to the correct target in the HUSS.

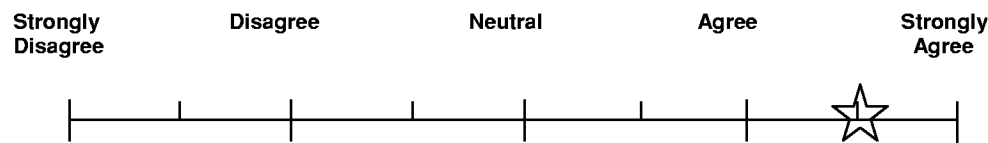
Pilot 2

- I. Question 1 to 6 are related to the display concept of Head-up Surveillance Symbology (HUSS) on the In-board-field-of-view (IFOV) display (see Figure 1). On the line that follows each question, please place a mark that corresponds to your response.

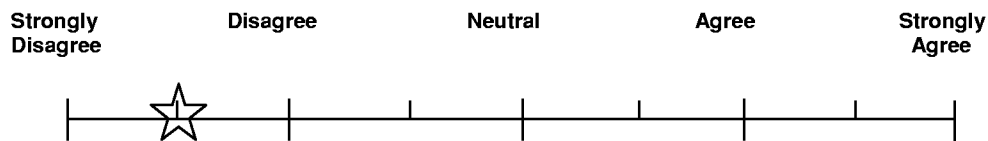
1. Adding HUSS on the IFOV display increases your ability to detect traffic.



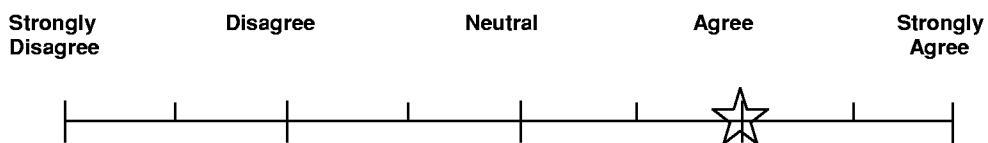
2. Adding HUSS on the IFOV display increases your ability to assess whether traffic was potentially threatening.



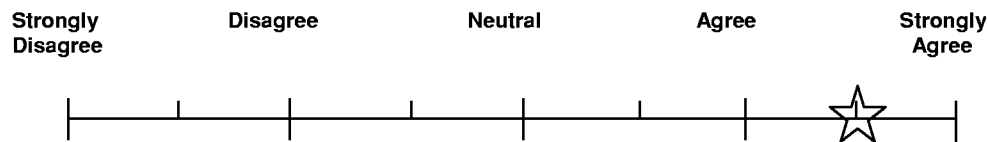
3. Adding HUSS on the IFOV display creates too much clutter on the display.



4. Adding HUSS on the IFOV display reduces workload.



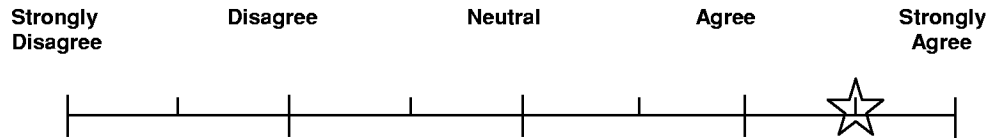
5. Adding HUSS on the IFOV display increases your awareness of traffic in the vicinity of the ownship.



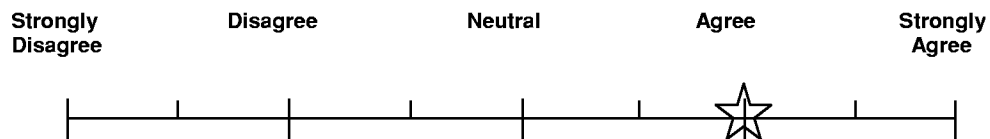
6. What is your general impression of having HUSS on the IFOV display?
It greatly enhances situational awareness in that display. Considering the lack of resolution (50 pixel/deg) and contrast available on XVS display at the present time. HUSS is essential to make the IFOV a useful tool.

II. Questions 1 to 6 are related to the Range Filter display concept. *The Range Filter allows HUSS information to be displayed on the PXD and/or IFOV, depending on the test condition, within a 7 n.m. boundary of the ownship.* On the line that follows each question, please place a mark that corresponds to your response.

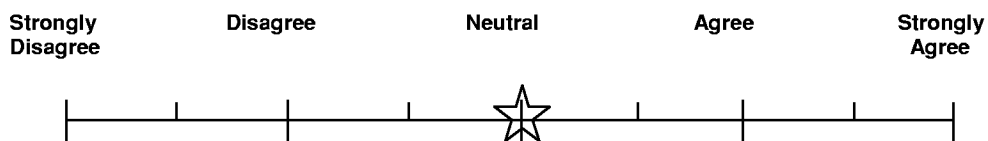
1. Adding a Range Filter increases your ability to detect traffic that is in close proximity to the ownship.



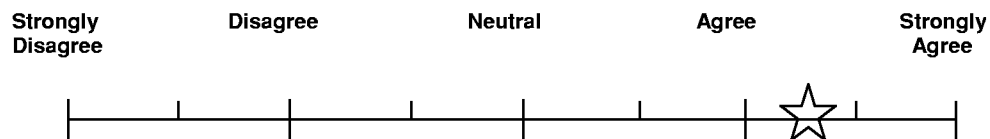
2. Adding a Range Filter increases your ability to assess whether the traffic was potentially threatening.



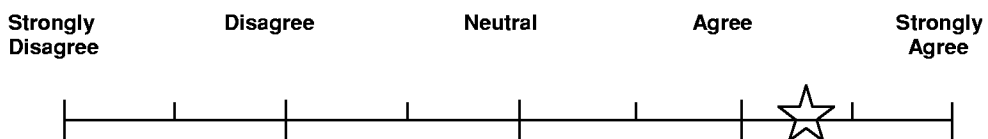
3. Adding a Range Filter creates too much clutter on the display.



4. Adding a Range Filter reduces workload.



5. Adding a Range Filter increases your awareness of traffic in the vicinity of the ownship.

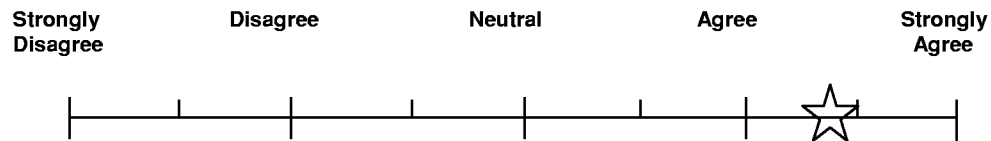


6. What is your general impression on the Range Filter display concept?
Clutter is certainly a concern for an XVS concept. However, having a decluttering feature will mitigate this problem. The ability to acquire traffic is a much larger problem. Since it seems unlikely that XVS will approach a real window for visual acuity in the near future, providing target acquisition symbology for the XVS is essential. The large filter reduces workload for the pilot in multi-target environment by automatically displaying proximate traffic.

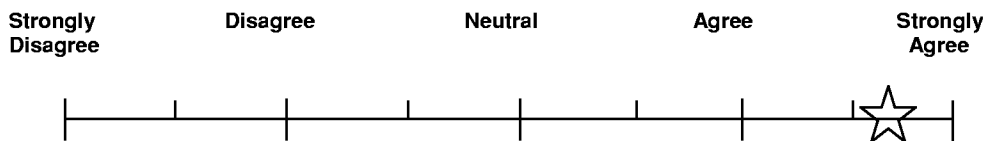
II. The following questions are related to both the display concepts of a 7 n.m. Range Filter on the XVS display* and HUSS on the IFOV display examined in this experiment:

**Note: XVS display refers to the combined use of the Primary XVS display (the primary head-up XVS display, or PXD), and the IFOV display. See Figure 2 below:*

1. The two display concepts examined in this experiment should be applied to both the approach and departure scenarios.

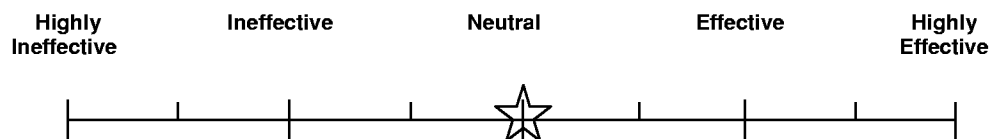


2. Traffic considered a threat or potential threat, i.e. TA and RA, should be transferred automatically from the Nav Display to the XVS display (i.e. the PXD and the IFOV display).

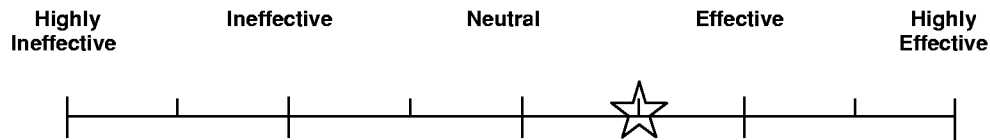


3. Please rate the overall effectiveness of the following display concepts for assessing and detecting traffic (see **Figure 2** for displays definitions):

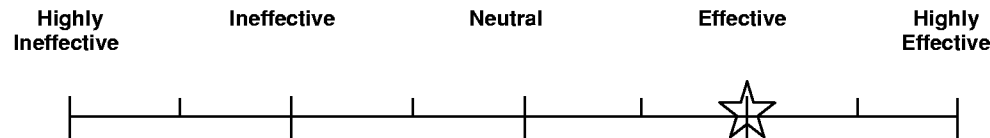
- a. **Without** HUSS on the IFOV and **Without** Range Filter on the XVS. *(This condition implies that the PXD contains only TA and RA categories information. There is no traffic information at all on the IFOV.)*



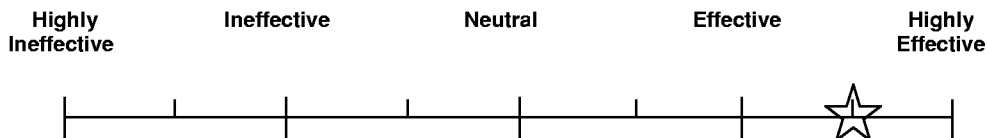
- b. **With** HUSS on the IFOV and **Without** Range Filter on the XVS. (This condition implies that both the PXD and the IFOV have TA and RA categories traffic information but there is no Proximate Traffic information on both the PXD and the IFOV displays.)



- c. **Without** HUSS on the IFOV and **With** Range Filter on the PXD. (This condition implies that only the PXD has a 7 n.m. Range Filter for displaying Proximate, TA, and RA categories traffic information. There is no traffic information at all on the IFOV.)



- d. **With** HUSS on the IFOV and **With** Range Filter on the XVS. (This condition implies that the Range Filter is applied to both the PXD and the IFOV for displaying Proximate, TA, and RA categories traffic information.)



4. Please discuss the **advantages and disadvantages** of the following display concepts. (See the previous page and Figure 2 for definitions of the terms.)

- a. **Without** HUSS on IFOV and **Without** Range Filter on XVS
Higher workload for the pilot since he must manually select ND targets (one at a time) for display on the XVS. Without HUSS on the IFOV, it is difficult to acquire traffic on the IFOV. Not as useful an overall concept as others.
- b. **With** HUSS on IFOV and **Without** Range Filter on XVS
IFOV much improved with HUSS as a tool for acquiring traffic. Workload higher without range filter. Better concept than "a".
- c. **Without** HUSS on IFOV and **With** Range Filter on PXD
IFOV not as useful for traffic detection without HUSS. Range filter very helpful on PXD, but HUSS needs to be on IFOV to be useful.

d. **With** HUSS on IFOV and **With** Range Filter on XVS

Best concept of all as long as pilot retains declutter capability.

5. Please provide additional comments, if there is any, regarding to this experiment.

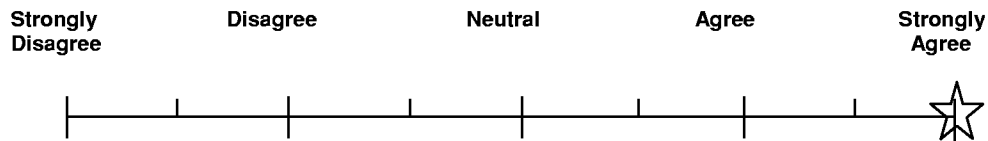
I thought that there were too many target aircraft concentrate too close together in this experiment even given the experiment objectives. A more realistic distribution of the aircraft would still have met the experiment objective in my opinion. Nevertheless, the objective were still met. The range filter concept is useful, but I would let the pilot have the ability to select the range based on traffic conditions and phase of flight (i.e., larger range for cruise at altitude when closure rates are much higher.) The IFOV HUSS is also a very useful if not essential tool.

The target aircraft appeared to me to be much closer than they were intended. This would manually have caused me to take evasive action. The targets may be drawn too large or there may be some other reasons that they appear closer than actual.

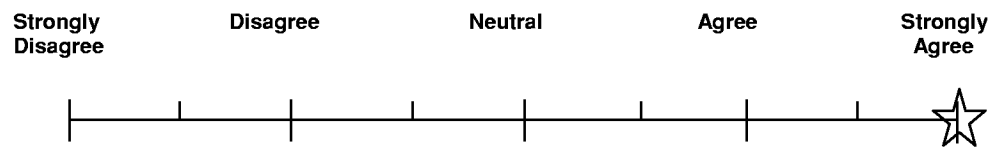
Pilot 3

1. Question 1 to 6 are related to the display concept of Head-up Surveillance Symbology (HUSS) on the In-board-field-of-view (IFOV) display (see Figure 1). On the line that follows each question, please place a mark that corresponds to your response.

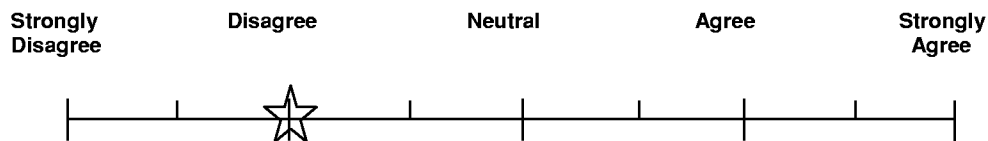
1. Adding HUSS on the IFOV display increases your ability to detect traffic.



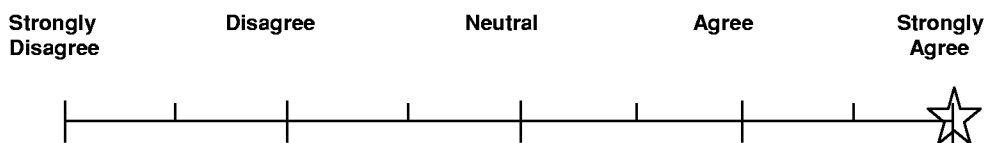
2. Adding HUSS on the IFOV display increases your ability to assess whether traffic was potentially threatening.



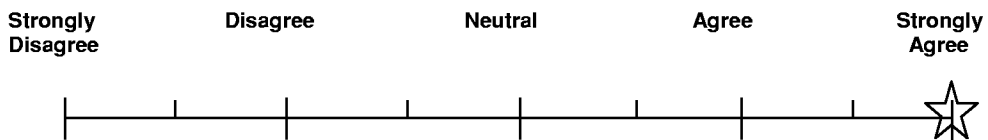
3. Adding HUSS on the IFOV display creates too much clutter on the display.



4. Adding HUSS on the IFOV display reduces workload.



5. Adding HUSS on the IFOV display increases your awareness of traffic in the vicinity of the ownship.

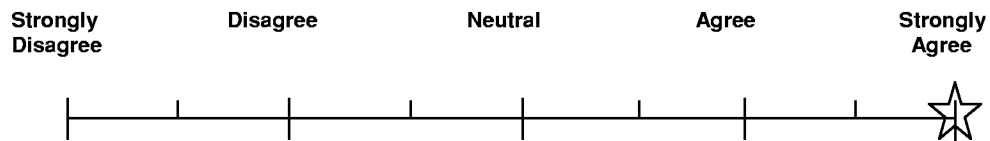


6. What is your general impression of having HUSS on the IFOV display?

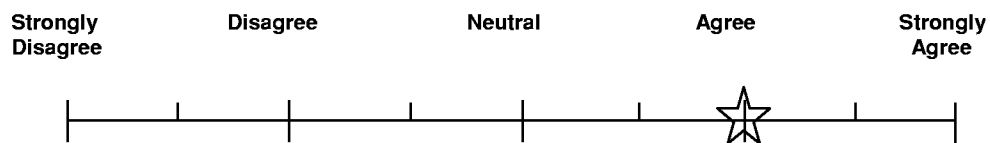
In general, very beneficial. Having HUSS on the IFOV should always be displayed with the same rules/properties as the PXD. I believe that the symbology actually decreases the workload. As to not have to search or hunt to distinguish a particular piece of traffic, on IFOV, very beneficial when turning towards that display.

II. Questions 1 to 6 are related to the Range Filter display concept. *The Range Filter allows HUSS information to be displayed on the PXD and/or IFOV, depending on the test condition, within a 7 n.m. boundary of the ownship.* On the line that follows each question, please place a mark that corresponds to your response.

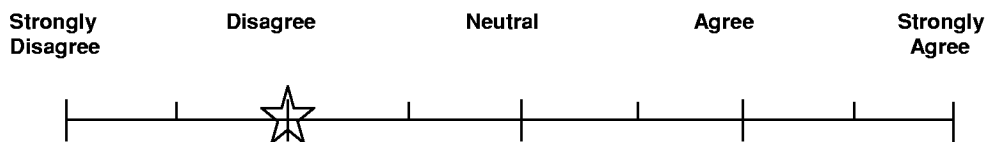
1. Adding a Range Filter increases your ability to detect traffic that is in close proximity to the ownship.



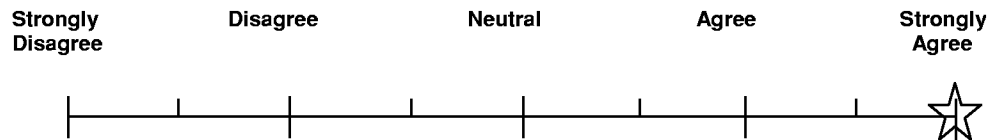
2. Adding a Range Filter increases your ability to access whether the traffic was potentially threatening.



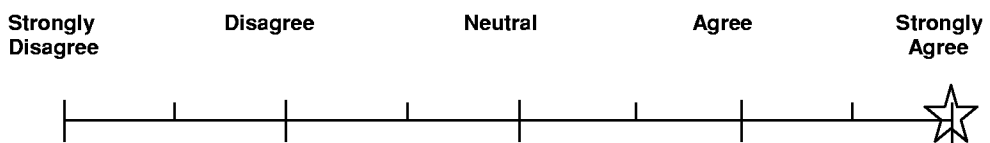
3. Adding a Range Filter creates too much clutter on the display.



4. Adding a Range Filter reduces workload.



5. Adding a Range Filter increases your awareness of traffic in the vicinity of the ownship.

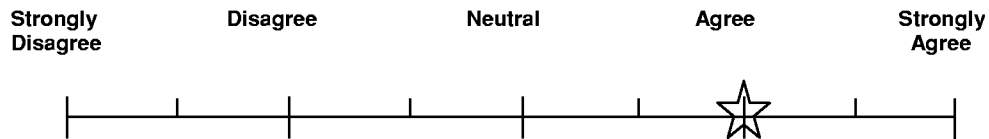


6. What is your general impression on the Range Filter display concept?
Very good concept. Large potential to decrease workload. Eliminates the requirement to manually select traffic to see symbol. A pilot variable range feature would be nice to declutter far off traffic. Same scale values as MAP, but not linked to scaling the MAP display. The two should be independent.

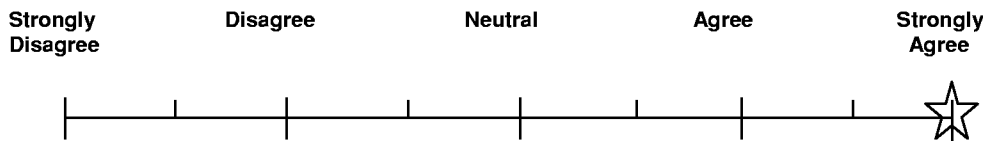
III. The following questions are related to both the display concepts of a 7 n.m. Range Filter on the XVS display* and HUSS on the IFOV display examined in this experiment:

**Note: XVS display refers to the combined use of the Primary XVS display (the primary head-up XVS display, or PXD), and the IFOV display. See Figure 2 below:*

1. The two display concepts examined in this experiment should be applied to both the approach and departure scenarios.

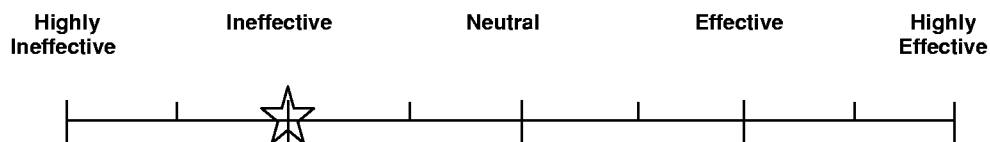


2. Traffic considered a threat or potential threat, i.e. TA and RA, should be transferred automatically from the Nav Display to the XVS display (i.e. the PXD and the IFOV display).

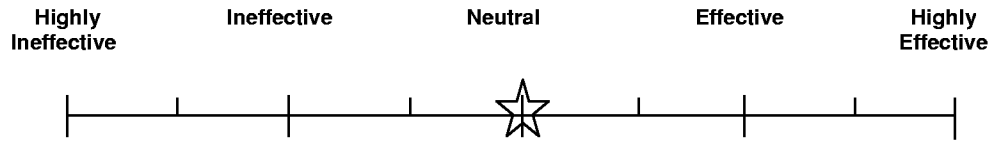


3. Please rate the overall effectiveness of the following display concepts for assessing and detecting traffic (see **Figure 2** for displays definitions):

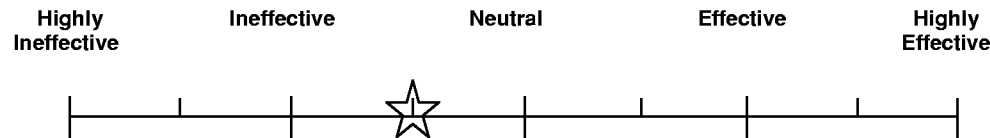
- a. **Without** HUSS on the IFOV and **Without** Range Filter on the XVS. (*This condition implies that the PXD contains only TA and RA categories information. There is no traffic information at all on the IFOV.*)



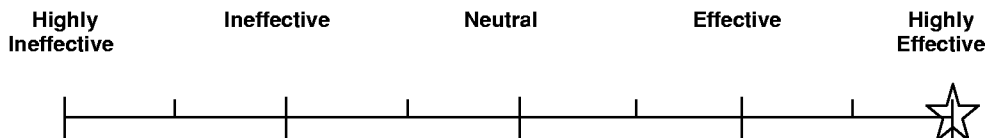
- b. **With** HUSS on the IFOV and **Without** Range Filter on the XVS. (This condition implies that both the PXD and the IFOV have TA and RA categories traffic information but there is no Proximate Traffic information on both the PXD and the IFOV displays.)



- c. **Without** HUSS on the IFOV and **With** Range Filter on the PXD. (This condition implies that only the PXD has a 7 n.m. Range Filter for displaying Proximate, TA, and RA categories traffic information. There is no traffic information at all on the IFOV.)



- d. **With** HUSS on the IFOV and **With** Range Filter on the XVS. (This condition implies that the Range Filter is applied to both the PXD and the IFOV for displaying Proximate, TA, and RA categories traffic information.)



4. Please discuss the **advantages and disadvantages** of the following display concepts. (See the previous page and Figure 2 for definitions of the terms.)

- a. **Without** HUSS on IFOV and **Without** Range Filter on XVS
In this configuration, the workload is increased to its highest. You are not using any auto aids to pick and identify traffic. While the display is good (in terms of HUSS), the lack of proximate traffic begins to render the display ineffective.
- b. **With** HUSS on IFOV and **Without** Range Filter on XVS
Same advantages of A, i.e. good display. Not being able to automatically track the proximate traffic, increases the workload.
- c. **Without** HUSS on IFOV and **With** Range Filter on PXD
No added advantage to this configuration. While the range filter is good, the lack of all traffic info on the IFOV is not. The biggest disadvantage is losing sight of (loss of symbology), of any traffic, especially TA/RA, is a disadvantage. Once it moves into the IFOV, it may still be a threat.

d. **With** HUSS on IFOV and **With** Range Filter on XVS

*This is the most advantages configuration. The only disadvantage **may** be the clutter. Some solutions would be a variable range and the ability to declutter all symbols **but** any TA/RA symbology.*

5. Please provide additional comments, if there is any, regarding to this experiment.

Velocity vectors on targets could be lower to give you a predictive idea whether they will stay in a display, or transition to another.

Amount of traffic seems excessive and unrealistic.

Same direction, converging traffic, would be a good test of the IFOV. (e.g. BWI)

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13. ABSTRACT (Maximum 200 words) The objective of this preliminary experiment was to investigate two head-up surveillance symbology (HUSS) display issues. The first issue was concerned with the benefits of adding a range filter to the current HUSS concept. A range filter limits the amount of traffic symbols displayed head-up by setting a range boundary (e.g., 7-nmi) around the ownship. The second issue was concerned with the need to incorporate HUSS in the inboard field-of-view (IFOV) display of the eXternal Visibility System (XVS) concept. The hypothesis tested was that adding a range filter to the XVS display and HUSS to the IFOV display would enhance the pilot's effectiveness in traffic surveillance tasks. Using a high-resolution graphics flight simulator, each of three pilots flew departure and arrival scenarios under visual meteorological conditions. The pilots' main tasks, while managing flight path, were to detect and assess potential airborne traffic hazards and to maintain overall situation awareness. Upon completing all the runs, each pilot completed a subjective questionnaire. Results showed that having both the HUSS on the IFOV and the range filter on each of the XVS displays enhanced the effectiveness of the XVS surveillance display concept. This configuration had the least head down time and the lowest mental workload. Combining both features gave the best target detection and, the earliest threat recognition performances, and enabled the pilots to create a better strategy for evasive action when it became necessary.				
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